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Implementation of Tidal Energy Extraction in a
Finite Volume Coastal Ocean Model
NERC Marine Renewable Energy Knowledge Exchange Programme 2014
Partner: Marine Scotland Science (MSS), Aberdeen
Supervisors: Dr Rory O’Hara Murray (MSS) and Dr Rob Harris (ICIT)
MSS Oceanography Group’s role in MRE

• One role of the Oceanography Group is to provide the scientific expertise to
  • Advise our Licensing colleagues about oceanographic aspects relevant to the licensing process (e.g. development license applications)
  • Assess the availability of MRE resources (tides, waves)
  • Quantify the potential impact of MRE developments (tidal, waves and offshore wind) on the physical environment
Personal background

Solid constitutive modelling
- structured cohesive soil
- unsaturated soil: multiphase continuum
- continuum thermomechanics:
  - free energy, internal state variables
  - invariance, objectivity
- material nonlinearity

Numerical methods
- explicit Runge-Kutta for state-based IVPs:
  - seismic structural dynamics
  - constitutive update
- multidimensional nonlinear minimization:
  - model parameter estimation

Structural dynamics
- seismic performance of frame structures:
  - geometric and material nonlinearity
- finite deformation of flexible shells:
  - kinematics

Programming
- structured/modular design:
  - high quality
  - suitable for research
- computationally efficient, robust

Computational fluid dynamics
- curvilinear, non-orthogonal coordinates
- depth-averaged tidal flow and transport

Mathematics
- pure, axiomatic, rigorous, abstract
- linear algebra
- differential calculus on normed vector spaces

Model construction using Tensor methods
Marine Renewable Energy

Background

- Oceanography Group at Marine Scotland Science (MSS): potential impacts of marine renewable energy developments
- Computational hydrodynamic models are the only way to obtain detailed flow information
- Finite Volume Method: the flow domain is subdivided into a finite number of discrete cells; the continuous flow field is represented by a finite set of values
- Discretized balance equations are solved numerically: accuracy, mesh dependency, stability, computational efficiency
Marine Renewable Energy

Background

• Model simulation of coastal ocean flows requires considerable expertise: problem definition, data input, interpretation of the results

• Modelling of tidal stream energy extraction is relatively new: limitations of different modelling approaches and validity of numerical simulations with respect to future energy extraction scenarios, are largely unknown

• Different scales of motion: small-scale flows (turbulence and swirl) may be significant for environmental processes (transport of sediment and nutrients), but with a relatively minor effect on energy resource
Implementation of Tidal Energy Extraction in a Finite Volume Coastal Ocean Model:

Objectives

- Rational approach to the assessment of numerical simulations: continuum balance equations; numerical approximation
- Basis for comparison of different modelling studies
- Physical principles governing energy extraction in general
- Specific details for the Finite Volume Coastal Ocean Model (FVCOM)
- Flexible user facility for the representation of tidal turbines
- Allow for future model development: swirl and turbulence; turbine control strategies
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Activities

- 3D modelling: sigma-coordinates: additional resistance has to be represented over the appropriate region of the water column
- 2D modelling: vertically-integrated balance equations: flow resistance may be treated as locally enhanced bed roughness
- 1D modelling: cross-channel integration; each cross-section is represented as a point in a 1D domain
- 1D model derivation gives insight into integration process inherent in discrete models general: second order variations give rise to ‘Reynolds stresses’ and similar terms (not necessarily turbulent)
- Gives insight into the fundamental nature of discrete model equations, as ‘filtered’ forms of the continuum equations
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Activities

• Idealized channel model: broadly representative of the Pentland Firth; study a range of conditions and energy extraction scenarios

• Compare results with 1D model applied to the same problem: use the comparison to illustrate capabilities and limitations of simple models

• Clarify the mathematical foundations: continuum balance, discretization, coordinate systems; simple and clear formulation, allowing for a consistent and rigorous comparison of different models

• Investigate and document the structure of the FVCOM source code: clarify details of solution algorithms; learn how best to implement new features

• Literature review: tidal stream energy extraction in particular; computational and mathematical techniques in general
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Benefits of the Experience

• Sharp practical focus for application of abstract mathematical approach of my PhD studies (sub-mesoscale tidal flow modelling and the effects of tidal stream energy extraction)

• Regular close contact with my supervisor Dr O’Hara Murray

• Informal discussions with staff and students at MSS

• Group seminars and meetings

• MSS library

• Aberdeen University: lectures and library access

• St Andrews University: Scottish Fluid Mechanics Meeting
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Benefits to MSS

• Systematic and rigorous approach to the question of modelling in general: detailed technical report helpful to others engaged in similar work
• Basis for objective assessment of merits and limitations of various modelling studies
• Improved understanding of detailed internal workings of FVCOM: modelling issues, practical solutions
• Closer working links with Heriot-Watt University: better communication, awareness of future collaboration potential
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Ongoing and Future Work

• 3D energy extraction model development is ongoing. This is a crucial part of the MSS modelling system in respect of future assessments.

• Basic facility is restricted to linear momentum effects. Subsequent PhD work will build on this by modelling other processes: swirl, turbulence, mixing.

• Potential for improvements in computational efficiency: adaptive numerical methods with error estimation.